NASA-CR-54390



# STUDIES OF ALKALI METAL CORROSION ON MATERIALS FOR ADVANCED SPACE POWER SYSTEMS

**Quarterly Progress Report No. 3**
**For Quarter Ending March 26, 1965**

By

R.W. HARRISON

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-6012

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Office of Scientific and Technical Information
Washington 25, D.C.
Attention: AFSS-A

# STUDIES OF ALKALI METAL CORROSION ON MATERIALS FOR ADVANCED SPACE POWER SYSTEMS

QUARTERLY PROGRESS REPORT 3

Covering the Period

December 26, 1964 to March 26, 1965

Written by

R. W. Harrison

Approved by
J. W. Semmel, Jr.
Manager, Materials and Processes

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-6012

Technical Management
NASA - Lewis Research Center
Space Power Systems Division
Mr. R. L. Davies

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

CONTENTS

ILLUSTRATIONS

## ILLUSTRATIONS (Cont'd)



## TABLES

# I. INTRODUCTION

The program reviewed in this third quarter progress report, covering from December 26, 1964 to March 26, 1965, is sponsored by the National Aeronautics and Space Administration. Its purpose is to examine the influence of stress on the corrosion behavior of an advanced refractory alloy in potassium (Task I) and to investigate corrosion mass transfer effects in a stainless steel-columbium alloy-potassium system (Task II).

## Task I

While there is considerable evidence that refractory alloys have excellent corrosion resistance to potassium, there are few experiments which describe the possible effects of stress on corrosion when the stress is sufficiently large to produce substantial amounts of creep during the test. It is appropriate for comparative purposes to study an advanced refractory alloy which has demonstrated excellent corrosion resistance to refluxing potassium during long-time exposures conducted at relatively low stresses at 2000°F. In this regard, D-43 columbium base alloy, in the form of welded capsules, has been tested in potassium under refluxing conditions for periods of 5,000 and 10,000 hours at temperatures on the order of 2000°F (Ref. 1) and has been selected for inclusion in this program.

The D-43 alloy reflux capsules will be tested under conditions which result in about 5 to 10% strain during a 500- to 2,000-hour exposure period in the 2000° to 2200°F temperature range. The reflux capsules used in this study will be of similar size to those previously described (Ref. 1). The capsule wall is reduced in the potassium liquid region and in the vapor condensing region to provide gauge sections where the extent of creep can be measured. Moderate temperature adjustments can be made during the test to achieve the desired strain-time conditions.

## Task II

The use of stainless steel, rather than refractory alloys, for power plant radiator construction and for the lower temperature portion of experimental facilities constitutes material and fabrication cost savings. Two methods of employing this approach are: use of co-extruded, stainless steel shell-refractory alloy core, tubing in the radiator or use of an all stainless steel radiator joined to the system by a bimetallic joint. Although the latter approach is preferred considering cost and problems associated with fabrication and joining of co-extruded tubing, a major uncertainty and limitation arises from the mass transfer of interstitial elements from the stainless steel to the refractory alloys through the alkali metal.

It is well established that the carbon and nitrogen transfer from Type 316SS to Cb-1Zr alloy at temperatures near 1500°F (Ref. 2). While some important aspects of this mass transfer behavior have been examined, several critical details require additional investigation. There is a need to define acceptable time and temperature conditions of operation in terms of maintaining satisfactory performance of the refractory alloys, such as Cb-1Zr alloy. Also, there are certain metallurgical aspects of this behavior which should be investigated in an effort to eliminate or reduce the mass transfer rate. In the latter category, it is most appropriate to consider the stabilization of carbon and nitrogen in the stainless steel by the addition of metallic elements which form carbides and nitrides of high thermodynamic stability. Commercially available, titanium stabilized, Type 321SS is one such alloy. A comparative investigation of this alloy and Type 316SS should indicate the ability of the titanium addition to reduce or eliminate interstitial mass transfer in a stainless steel-Cb-1Zr alloy bimetallic system. Columbium-1% zirconium alloy specimens have been exposed to liquid potassium in Type 321SS and Type 316SS capsules for 1,000 hours at 1400°F under isothermal conditions to evaluate this premise.

## II. SUMMARY

During the third quarter of this program, the topics abstracted below were covered. The results are interpretatively presented in this report.

<u>Task I - Stress Corrosion Reflux Capsule Tests</u>

A D-43 alloy reflux stress-corrosion capsule was fabricated, filled with purified potassium, sealed and installed in the test facility.

Assembly and instrumentation of the Task I test facility was completed and the system was evacuated to a pressure of 2 x $10^{-8}$ torr prior to the bakeout cycle. The initiation of the test is pending receipt of tungsten caps which are to be installed over the $Al_2O_3$ probes to prevent any possible reaction between the $Al_2O_3$ and the D-43 alloy.

<u>Task II - Bimetallic Isothermal Capsule Tests</u>

Two Type 321SS and two Type 316SS capsules, each containing two Cb-1Zr alloy test specimens, were tested isothermally at 1400°F for 1,000 hours without difficulty. Post-test evaluation of capsules has shown that Type 321SS has a significant advantage over Type 316SS in refractory metal-stainless steel-potassium systems in inhibiting mass transfer of the interstitial elements carbon and nitrogen from the stainless steel to the refractory metal.

## III. TASK I - STRESS CORROSION REFLUX CAPSULE TESTS

### A. Capsule Fabrication and Filling

Approval was received from the NASA Technical Manager to incorporate a boiling nucleator in the D-43 alloy reflux capsule design. Subsequently, components for the nucleators were machined for each of the three D-43 alloy capsules; one complete capsule has been fabricated, Figure 1, leak checked, the welds radiographed and the capsule filled with potassium. The potassium was transferred directly to the capsule from the final hot trapping container and the capsule sealed by electron beam welding in a vacuum of $7 \times 10^{-6}$ torr. The potassium that was used for filling the capsule was sampled at the same time that the capsule was filled and analyzed for oxygen by the mercury amalgmation method; the results showed the oxygen in the potassium taken from the fill tube to be 5 ppm and the oxygen in the potassium taken from the chamber samples to be 8 ppm. The filled and sealed capsule was examined radiographically to assure a sound electron beam weld and subsequently was installed in the test facility.

### B. Test Facility

The high-vacuum LVDT's from Automatic Timing and Controls, Inc. and the high-purity alumina probes from American Lava Company were received during the report interim. In order to help minimize the pump-down time of the Task I facility as a result of outgassing, the LVDT's were heated to 650°F in a high pumping capacity vacuum furnace; after three hours at temperature, a vacuum of $1 \times 10^{-5}$ torr was achieved. The assembly of all the components in the high-vacuum chamber was completed on 2-24-65 and the system was closed and evacuated. Mass spectrometer leak checking indicated no leaks present and a pre-bakeout vacuum of $2 \times 10^{-8}$ torr was attained.

At the request of the NASA Technical Manager, the initiation of the test has been delayed pending installation of tungsten caps over the $Al_2O_3$ probes. The tungsten caps will be utilized as a precautionary measure to avoid the possibility of any deleterious reaction between the $Al_2O_3$ probes and the D-43 alloy capsule wall. The caps have been designed in order to be compatible with the existing $Al_2O_3$ probe configuration and the order placed. Delivery is expected on 4-2-65.

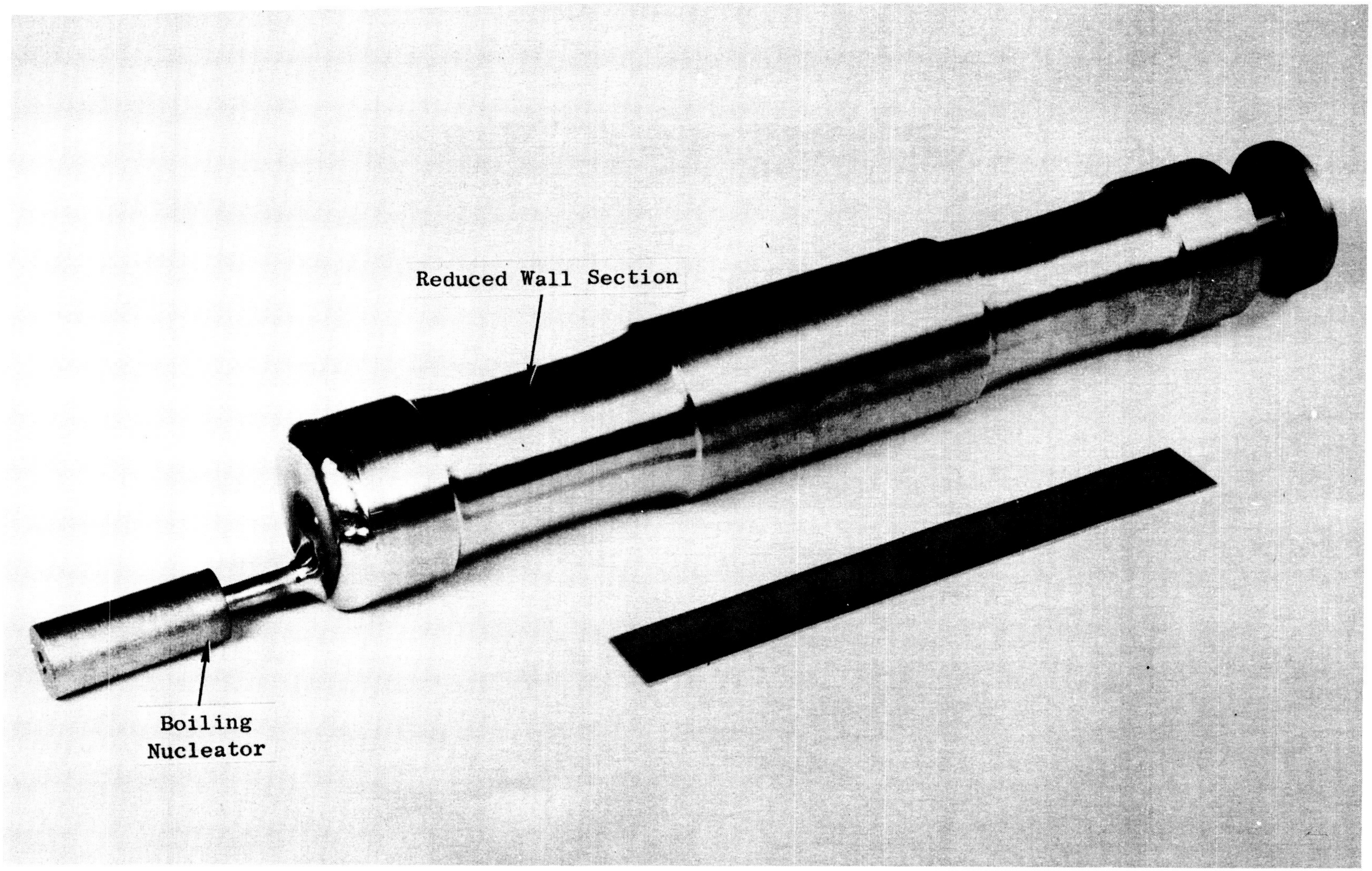


Figure 1. D-43 Alloy Reflux Corrosion Capsule Ready for Filling with Potassium. C65020211

The assembly of the strain measuring LVDT-probe units without the tungsten cap is depicted in Figures 2, 3 and 4. The stainless steel spring is utilized to maintain a negligible load contact of the probe on the capsule wall. The square hole in the stainless steel case and the square shank on the probe serve a similar purpose by preventing loss of contact by rotation of the probe. These assembled units are shown in place in the test facility in Figure 5. Adjustments in all planes are provided such that the probes can be located directly on the 0.020-inch thick reduced wall section of the capsule.

The capsule is supported in a Cb-1Zr alloy cup insulated from the support table by tantalum shielding; heating is achieved by use of a split tantalum element. The probes extend through the gap in this element to contact the capsule in the liquid zone, Figure 5. Final location of the probes on the 0.020-inch constant wall thickness in the liquid and condensing zones was achieved by use of a dial gauge, subsequent to adjustment of the capsules in the upper capsule support to maintain capsule verticality, Figure 6. The boiling nucleator is heated by means of a tantalum-sheathed resistance element which is shielded with tantalum sheet, Figure 7. The completed assembly for one capsule with tantalum shielding in place is shown in Figure 8. Using a similar configuration, it is possible to test two capsules simultaneously. Although not shown, the W-Re thermocouples were attached to a vacuum feedthrough, Figure 9, composed of W-25%Re and W-3%Re wires. A demodulator-recorder circuit, in conjunction with secondary LVDT bucking coils to be used as nulling devices, Figure 10, has been instrumented so that the strain can be recorded continuously. A deflection in the capsule wall as small as 0.0001 inch can be measured.

The first capsule test will be initiated under the conditions which were determined from the creep evaluation of the D-43 alloy bar procured for this program. The initial temperature has been established at 2200°F with subsequent adjustments, based upon the actual creep measurements made on the reduced section of the capsule wall, to achieve approximately 5% strain in 1,000 hours.

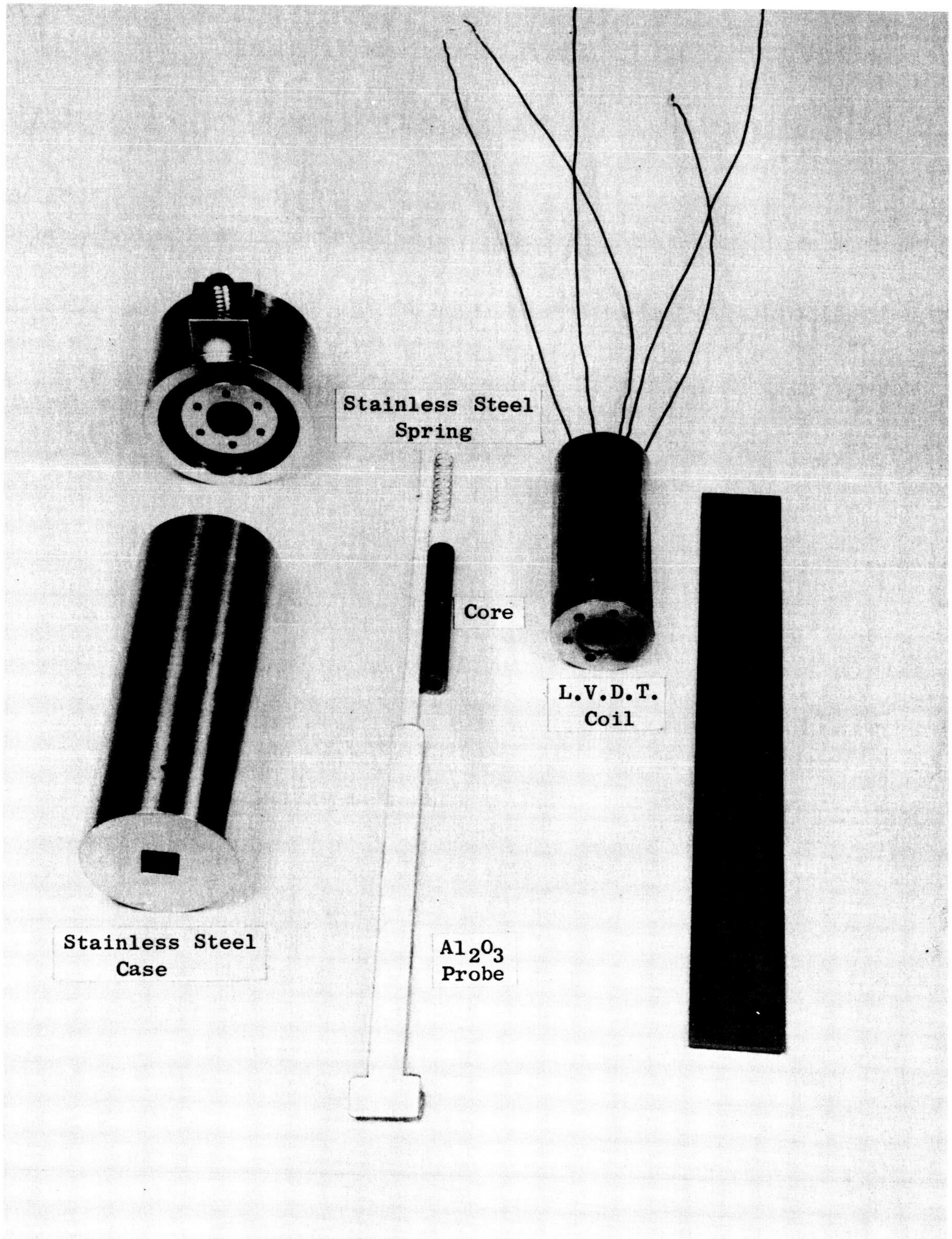


Figure 2. Disassembled Strain Measuring LVDT-Probe Unit. C65020208

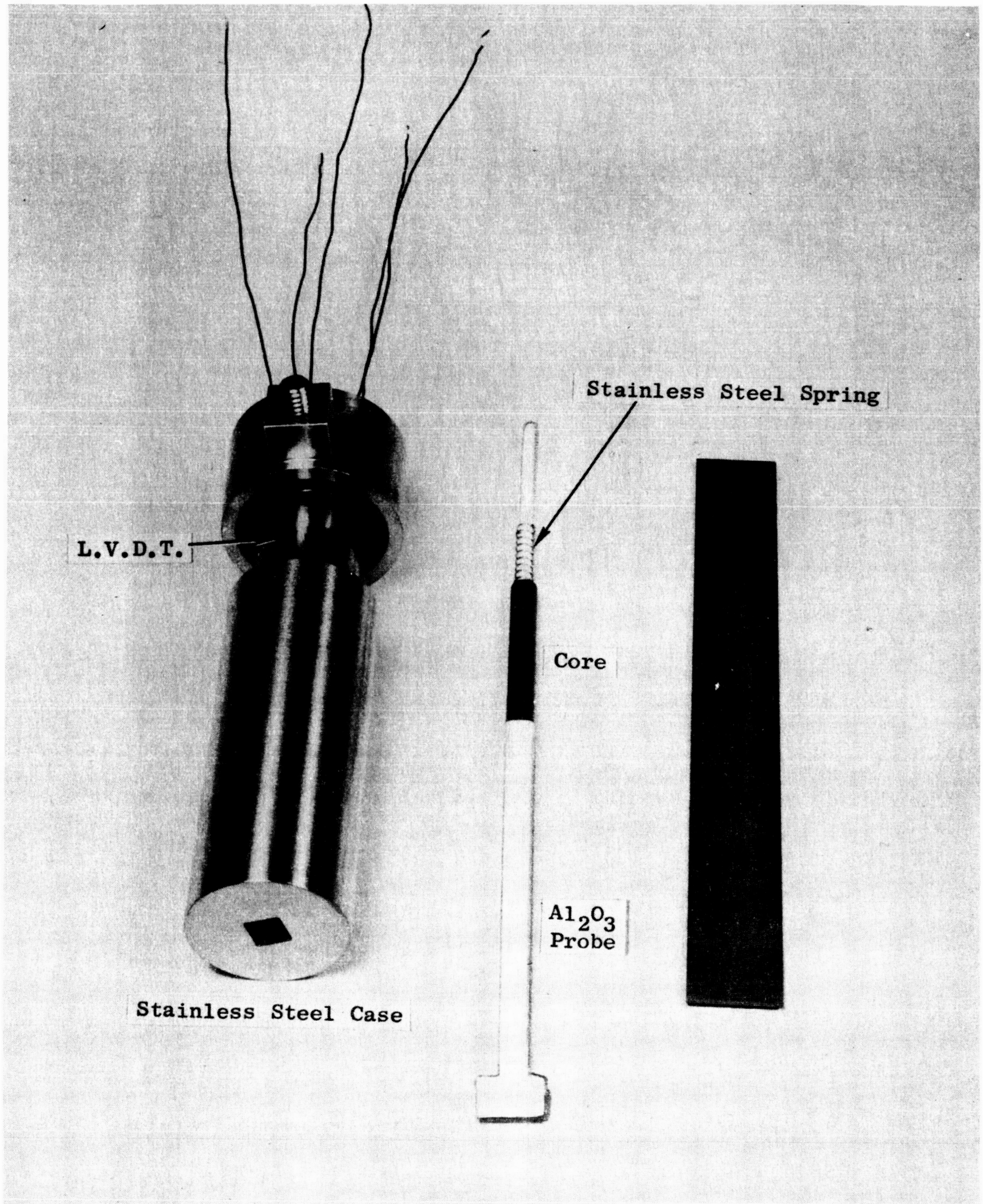


Figure 3. Partially Assembled LVDT-Probe Unit. C65020206

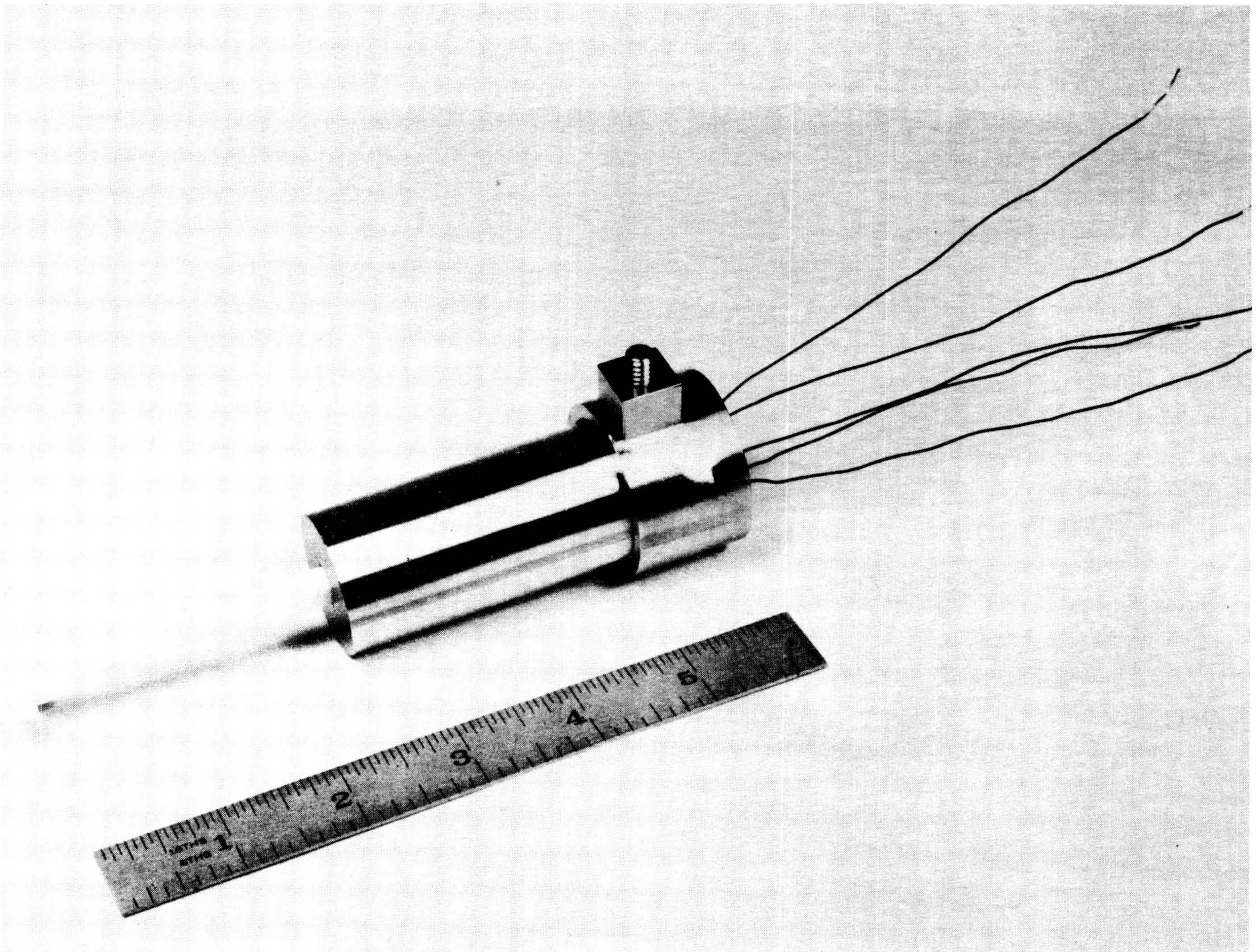

Figure 4. Assembled LVDT-Probe Unit for Strain Measurement. C65020210

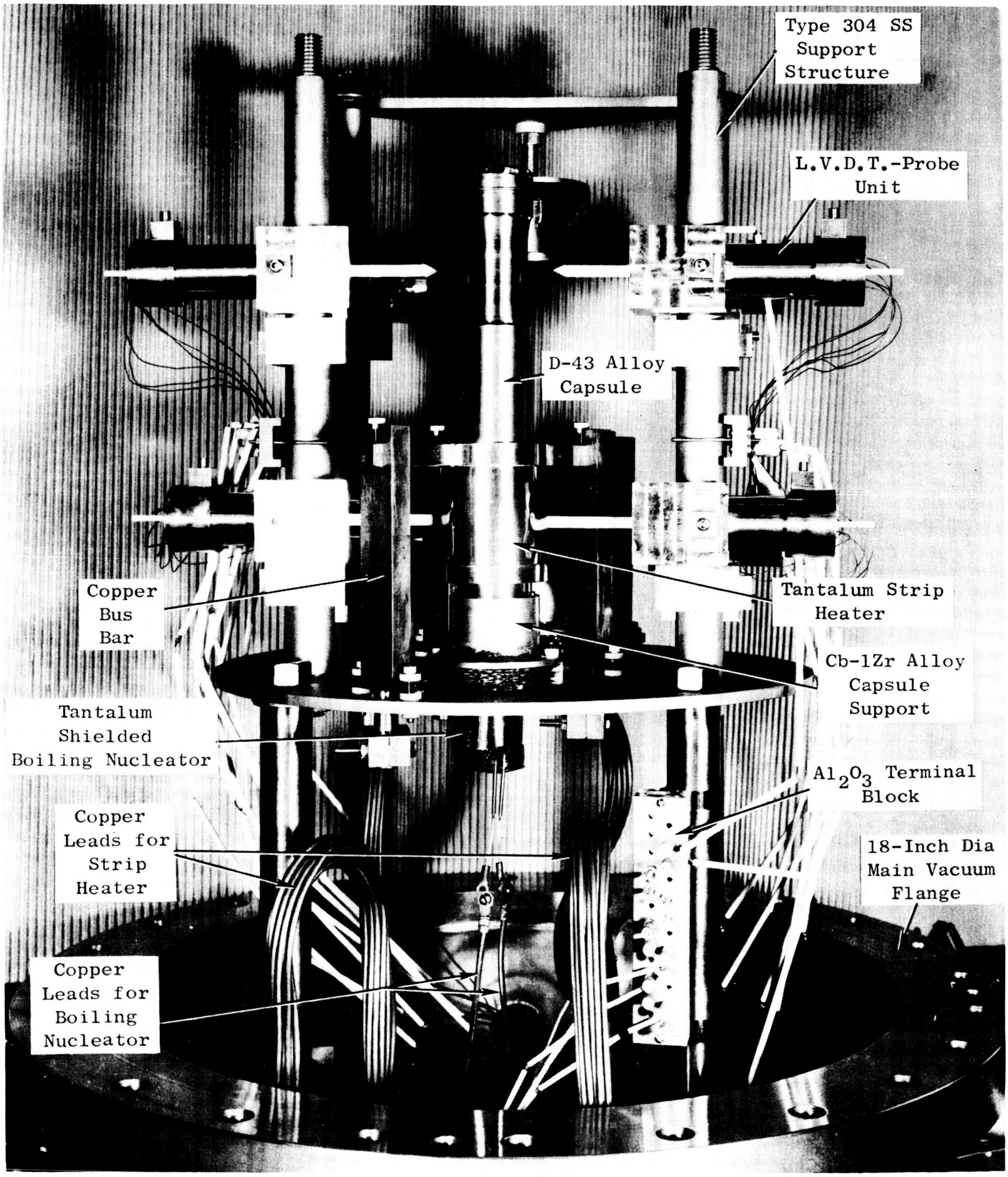


Figure 5. LVDT-Probe Units Installed with a D-43 Alloy Reflux Corrosion Capsule and Tantalum Strip Heating Element in Place in the High-Vacuum Chamber. Strain is Measured in the Condensing Zone and in the Liquid Zone. C65022603

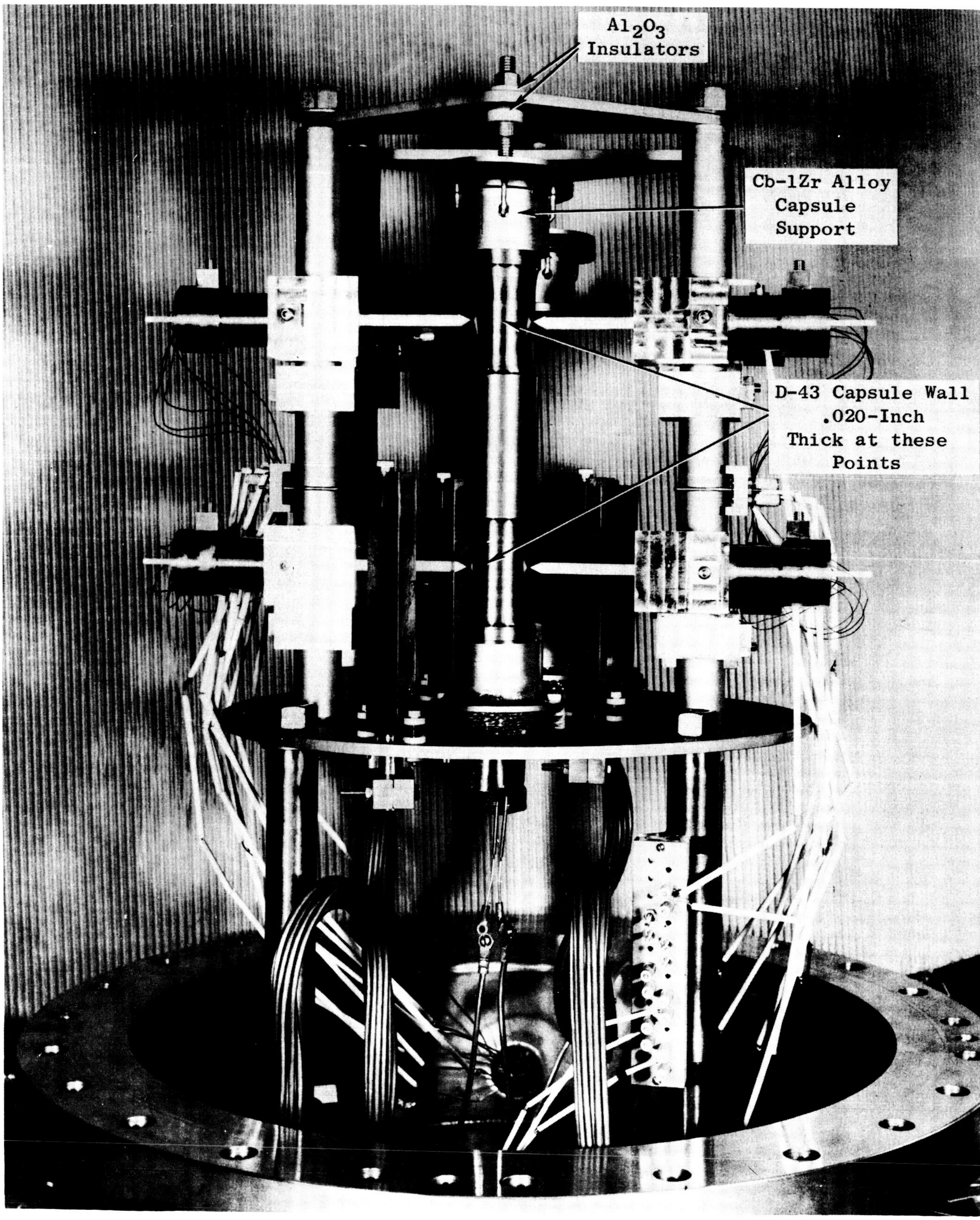


Figure 6. LVDT-Probes Located on Reduced Wall Section. Constant 0.020-Inch Thick Wall Section Located by Means of a Dial Gauge. Upper Cb-1Zr Alloy Capsule Support Maintains Verticality of Capsule and Lateral Position. C65022604

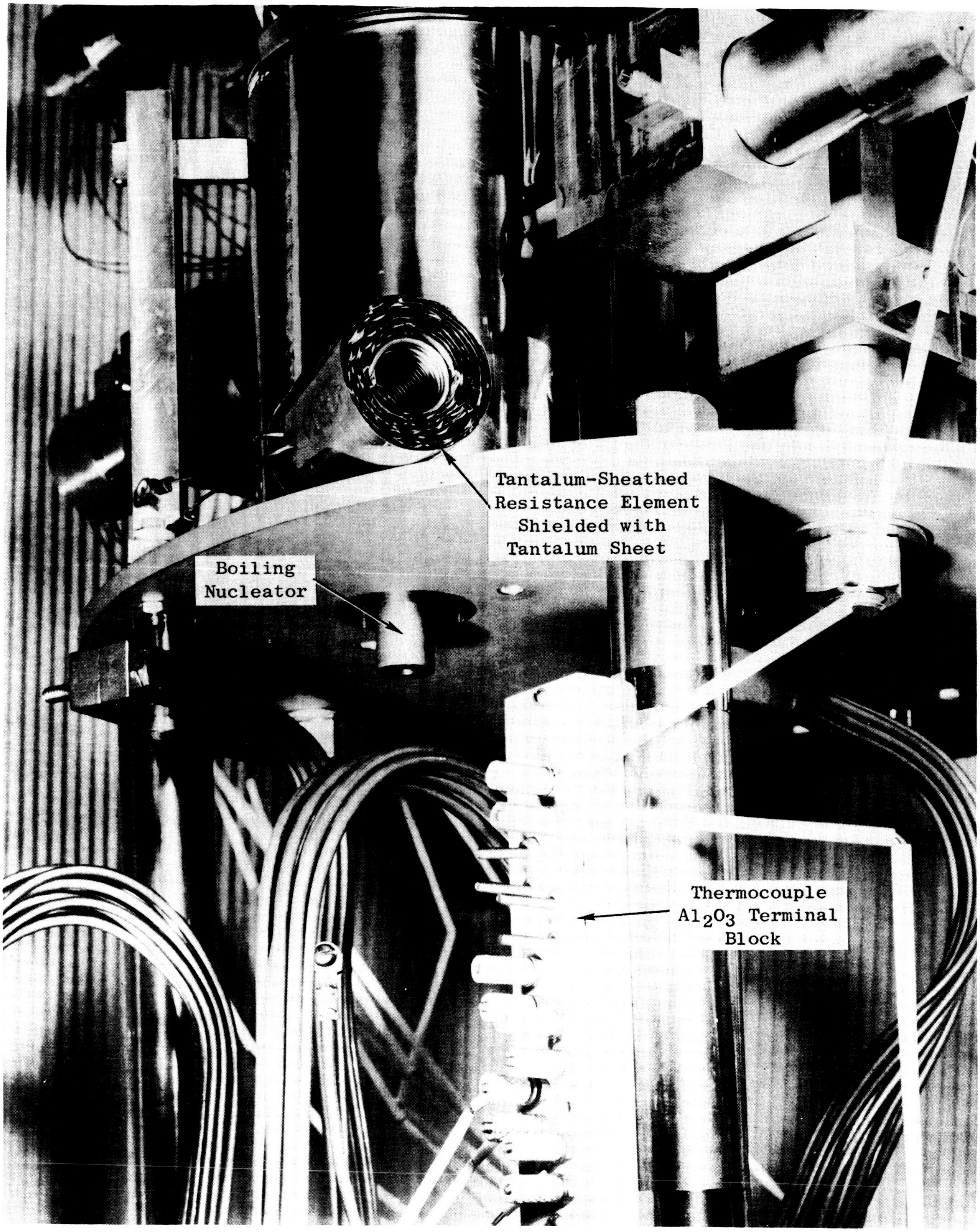


Figure 7. View of Bottom of D-43 Alloy Reflux Corrosion Capsule Extending Through Support Structure. The Boiling Nucleator is Heated by a Tantalum Sheathed Resistance Element. C65022608

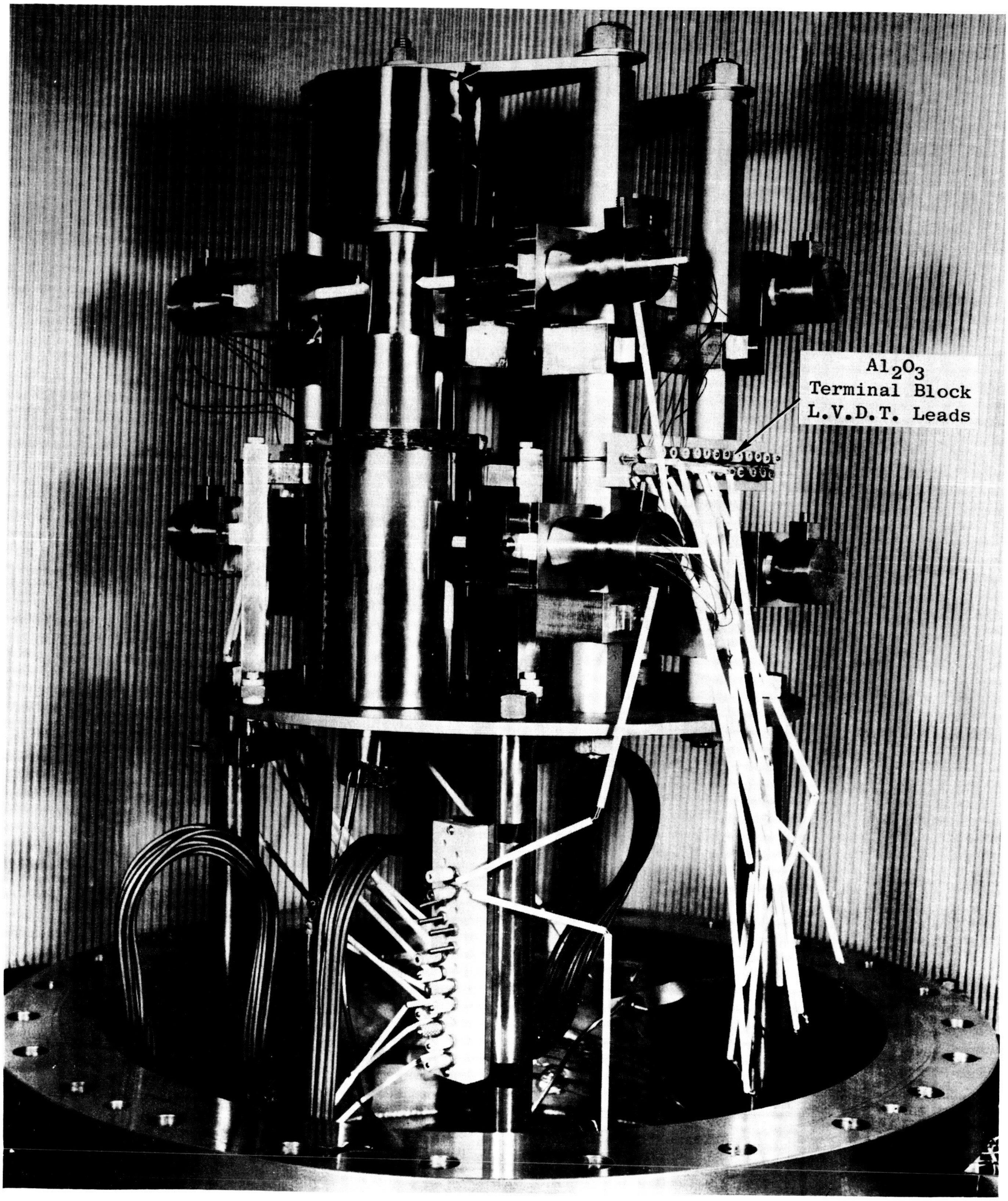


Figure 8. Completed D-43 Alloy Reflux Corrosion Capsule Assembly Showing all Tantalum Heat Shields in Place. Provision for Testing Two Capsules is Provided as Shown. C65022606

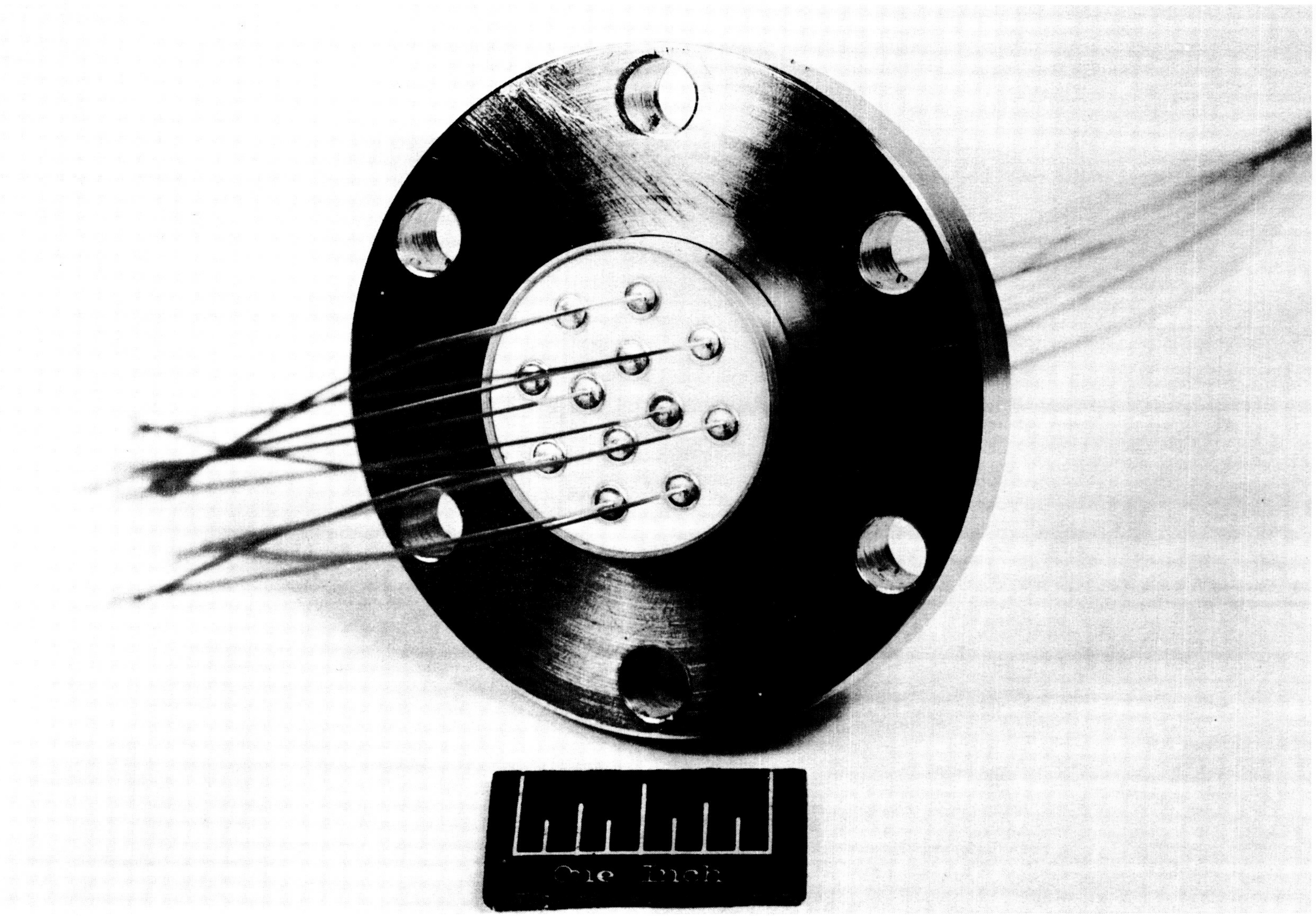


Figure 9. W-Re Feedthrough with Provision for Six W-25%Re vs W-3%Re Thermocouples. C64111836

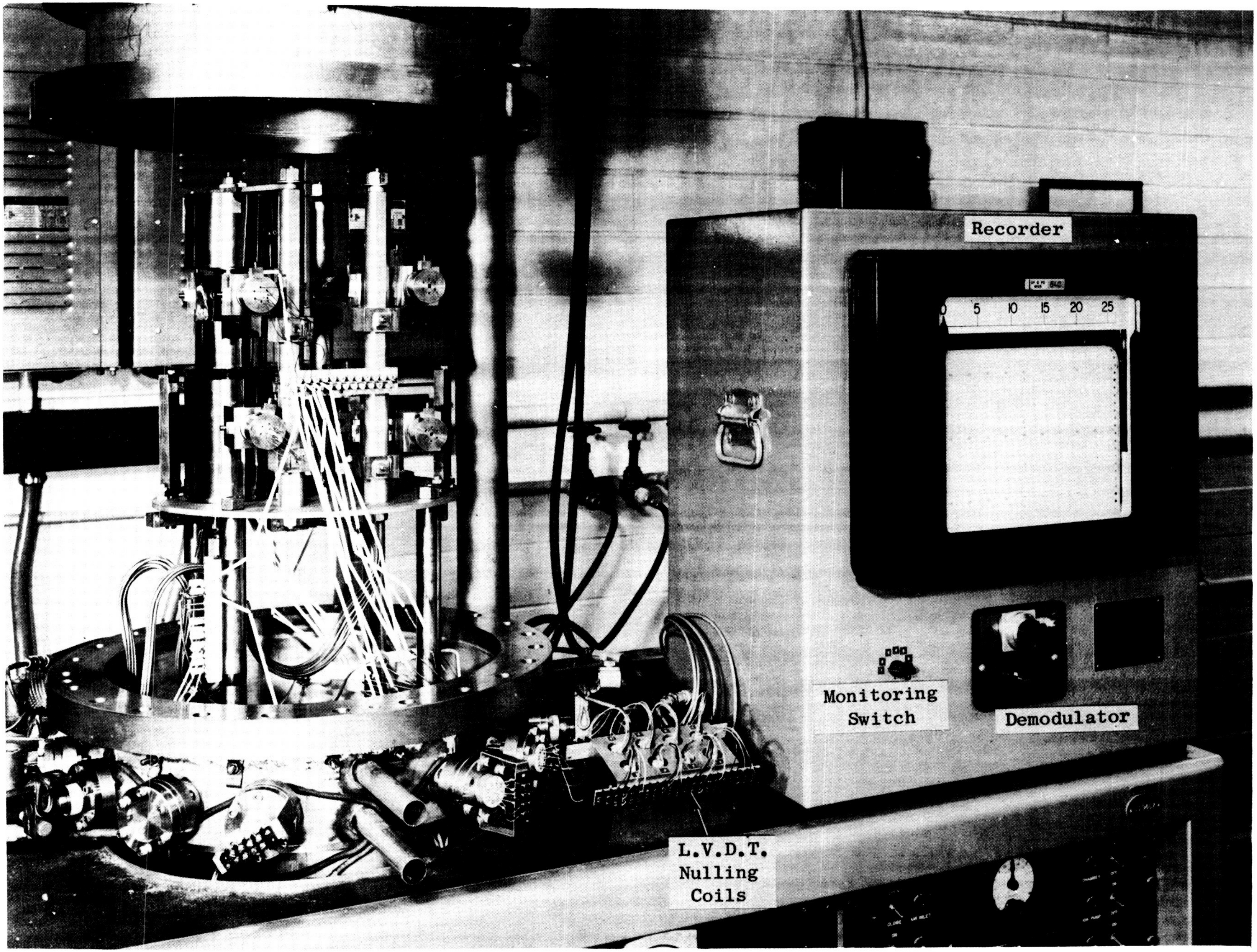


Figure 10. Test Facility to Measure Biaxially Induced Creep in D-43 Alloy Reflux Corrosion Capsules. C65022609

## IV. TASK II - BIMETALLIC CAPSULE PROGRAM

### A. Capsule Testing

Two Type 321SS and two Type 316SS capsules, each containing one stress-rupture and one tensile specimen of Cb-1Zr alloy sheet in potassium, were exposed for 1,000 hours at 1400°F in an air environment. A maximum temperature variance of 20°F from the mean temperature of 1405°F was measured for this time period. The mean temperature was calculated on the basis of temperature readings from seven beaded, chromel-alumel thermocouples spot welded to the sides of the capsules. A temperature differential of 20°F also was measured between the top and bottom of one capsule. The capsules were removed from the test facility and examined. As anticipated no leaking was evident and oxidation was minor, Figure 11.

### B. Test Evaluation

Post-test evaluation tests that have been completed on the stainless steel capsules and Cb-1Zr alloy test specimens have definitely indicated the advantages of Type 321SS over Type 316SS, with respect to mass transfer of the interstitial elements, for use in refractory alloy-stainless steel-potassium systems.

The stainless steel capsules were opened in an argon atmosphere and drained of potassium. After removal of the Cb-1Zr alloy sheet specimens, the capsules and specimens were cleaned and examined. No appreciable differences in appearance of the internal surfaces of any of the capsules were noted from visual observation, Figure 12. However, a definite discoloration was noted on the Cb-1Zr alloy specimens which were exposed in the Type 316SS, Figure 13, capsules. This discoloration was not evident on the Cb-1Zr alloy specimens exposed in the Type 321SS capsules. Also, a 300 ppm weight increase was measured for a specimen exposed in a Type 316SS capsule; no increase could be detected in a similar specimen exposed in a Type 321SS capsule.

Subsequently, the Cb-1Zr alloy specimens were analyzed for carbon, oxygen, nitrogen and hydrogen and the data are presented in Table I. The chemical analyses further clarify the preliminary observation. Negligible changes in nitrogen and carbon

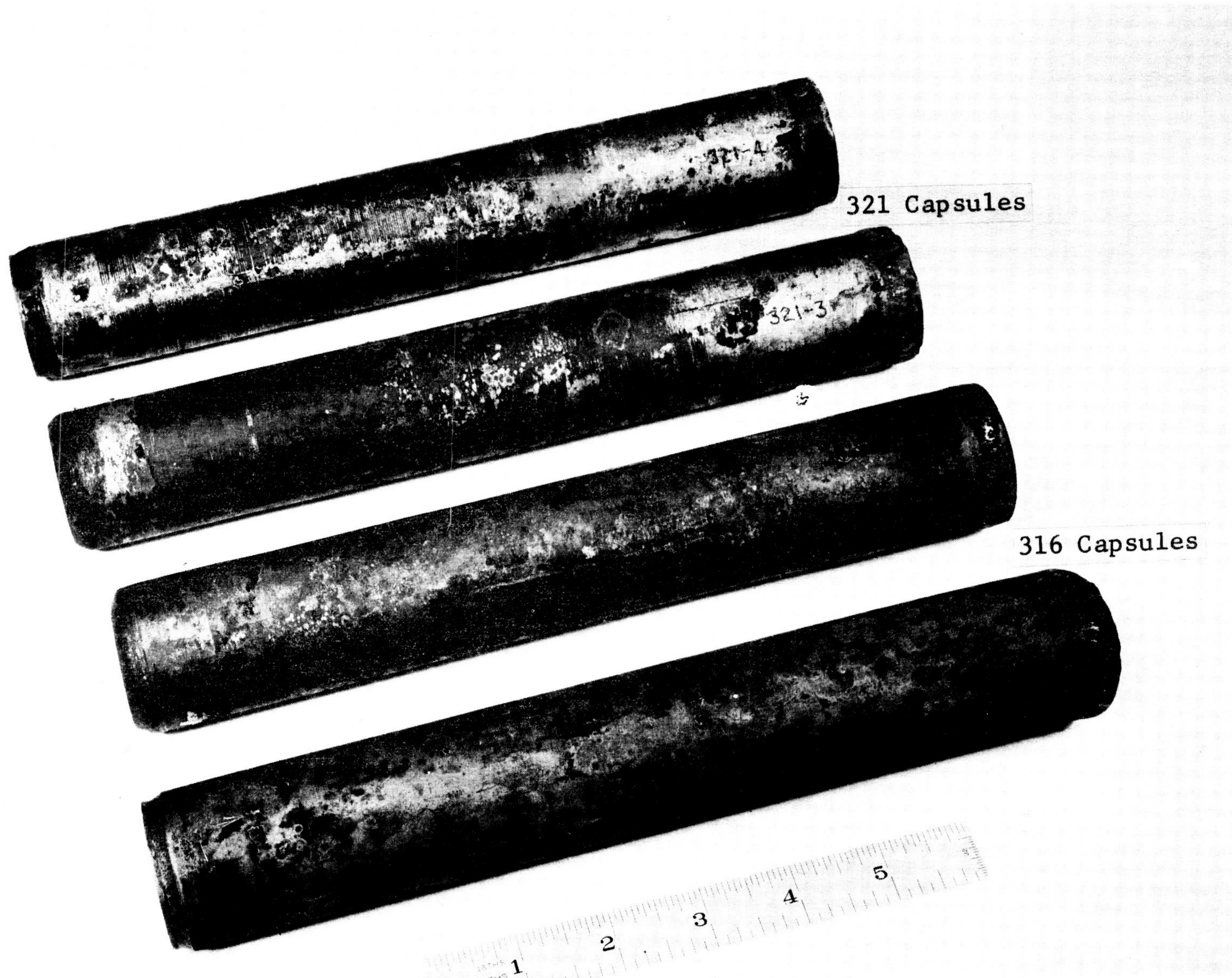


Figure 11. Type 316SS and Type 321SS Isothermal Corrosion Capsules, Containing Potassium and Cb-1Zr Alloy Test Specimens, After Being Exposed for 1,000 Hours at 1400°F in Air.

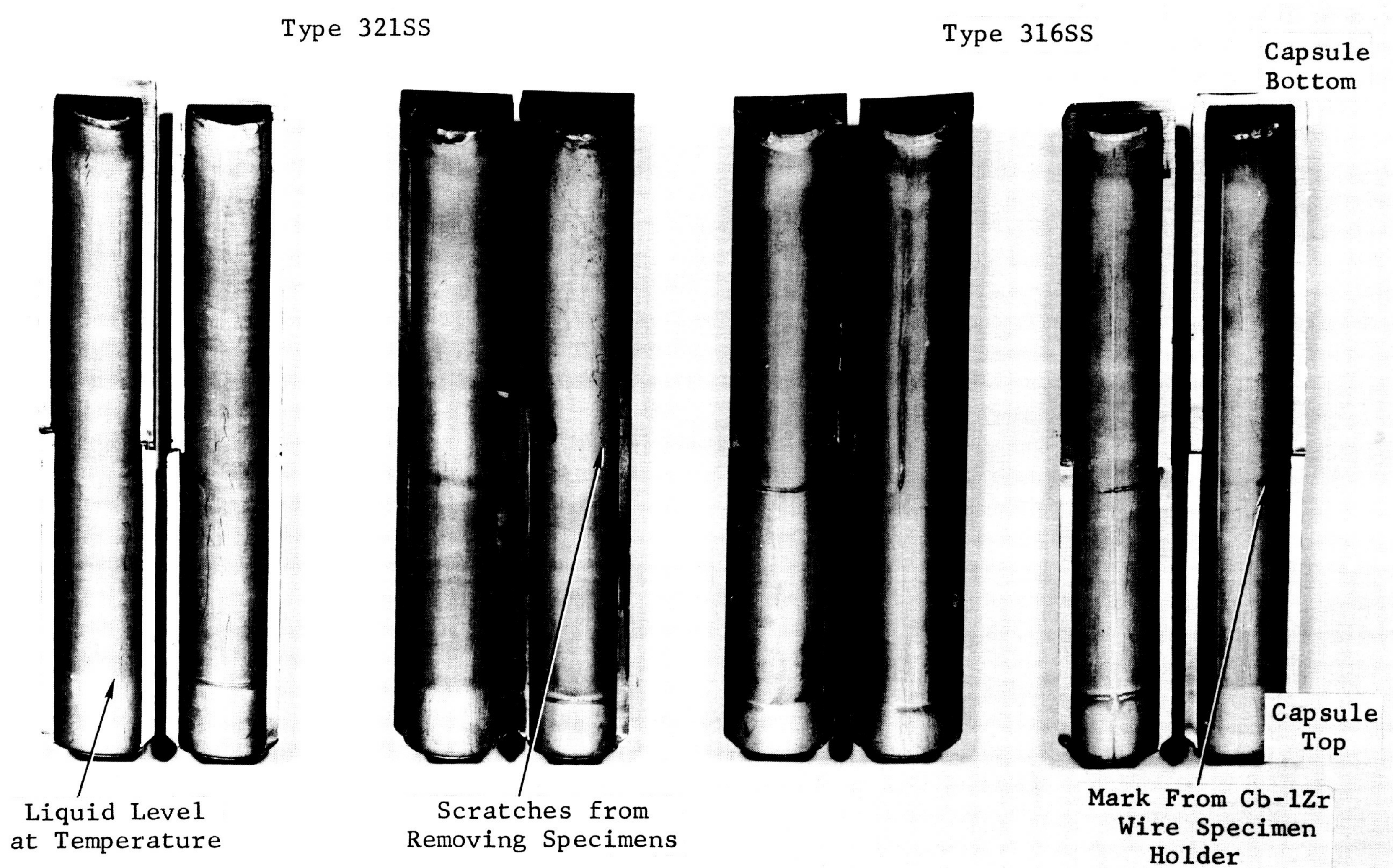


Figure 12. Sectioned Type 316SS and Type 321SS Isothermal Corrosion Capsules After Being Exposed to Potassium for 1,000 Hours at 1400°F.

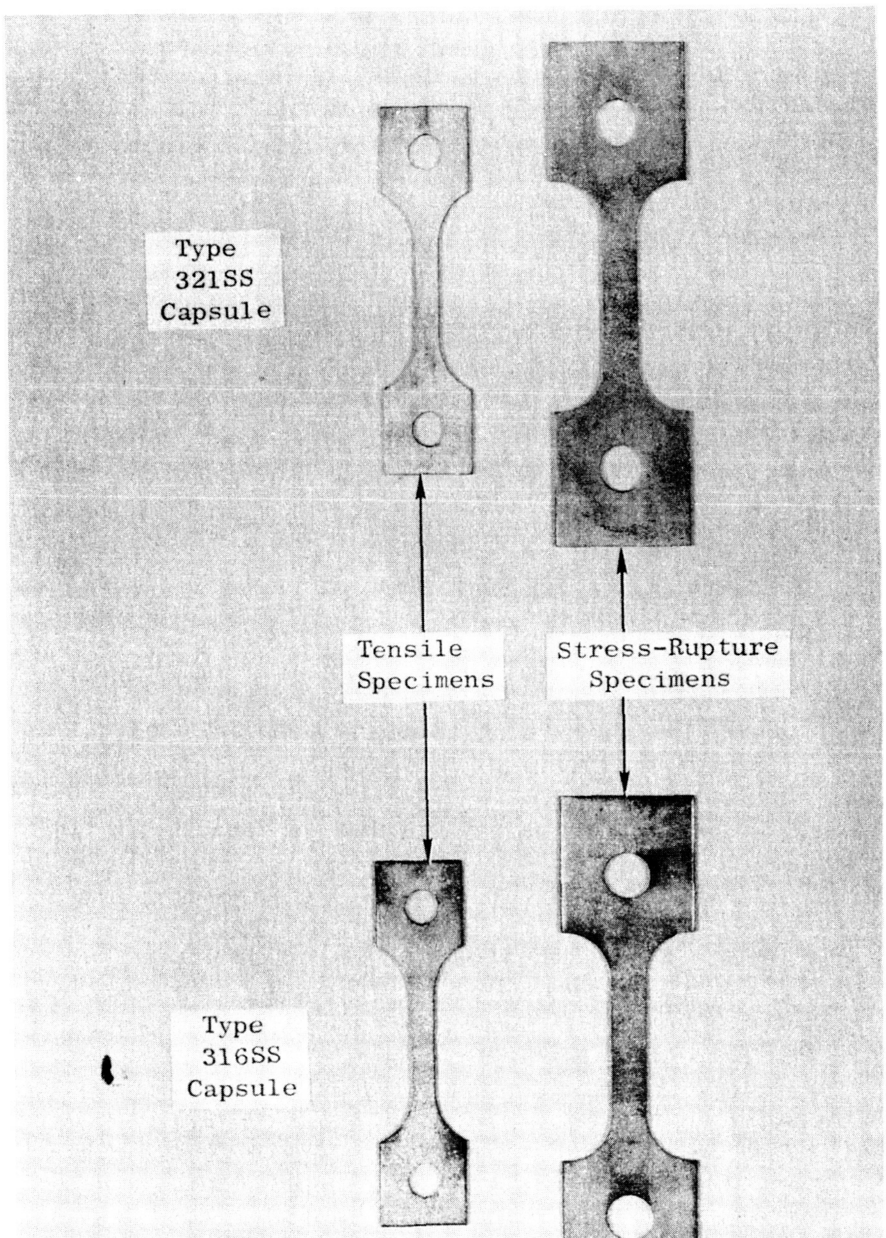


**Figure 13.** Cb-1Zr Alloy Tensile and Stress-Rupture Sheet Specimens Exposed for 1,000 Hours at 1400°F in Potassium Contained in Type 316SS and Type 321SS Capsules. Definite Discoloration can be Noted on Specimens Exposed in a Type 316SS Capsule. C65021112

## TABLE I

## POST-TEST CHEMICAL ANALYSES OF 0.040-INCH THICK Cb-1Zr ALLOY SPECIMENS EXPOSED FOR 1,000 HOURS AT 1400°F IN POTASSIUM CONTAINED IN TYPE 321SS AND TYPE 316SS CAPSULES

| Capsule Material and Specimen No. | Chemical Analyses of Cb-1Zr Alloy Specimens(1), ppm C(2) | N(3) | O(3) | H(3) |
|---|---|---|---|---|
| Type 316SS-1 | 210 | 206 | 258 | 23 |
| Type 316SS-2 | 280 | 336 | 156 | 7 |
| Type 321SS-3 | 50 | 21 | 147 | 13 |
| Type 321SS-4 | 35 | 16 | 114 | 14 |
| Pre-test-1(4) | 10 | 14 | 75 | 6 |
| Pre-test-2(5) | 50 | 50 | 200 | 24 |

---

(1) MCN 454

(2) By Combustion Conductometric Techniques.

(3) By Vacuum Fusion Techniques.

(4) Conducted for Incoming Material Quality Control Purposes on 9-8-64.

(5) Conducted as Companion Analysis at the Same Time the Analyses were Performed on the Specimens Exposed to Potassium (2-15-65).

contents were noted in the Cb-1Zr alloy specimens exposed in Type 321SS capsules as compared to the significant transfer of carbon and nitrogen that occurred in the Type 316SS capsules. There is no pronounced difference in the oxygen content of the Cb-1Zr alloy specimens exposed in either the Type 316SS or the Type 321SS capsules. The increased nitrogen and carbon contents of the Cb-1Zr alloy specimens tested in Type 316SS capsules significantly affected the room temperature tensile properties as evidenced by the higher yield strengths and the lower tensile elongation, Table II.

Expectations are that the results reported here have far reaching implications beyond the scope of this investigation. By appropriate employment of carbide-nitride forming alloying additions, such as titanium in Type 321SS, the transfer of nitrogen and carbon may be prevented or substantially reduced in a variety of systems and applications. A few examples of areas where this technique may be employed effectively are: 1) to reduce the outgassing of carbon and nitrogen from alloys exposed to high temperatures in high-vacuum systems, 2) to reduce the diffusion of carbon and nitrogen from the stainless steel to the refractory metal in coextruded tubing, and 3) to reduce the mass transfer of carbon and nitrogen that is induced by thermal gradients in certain monometallic systems which contain alkali metals. The latter case is of particular interest, inasmuch as carbon and nitrogen transfer have been observed in alloy steel, stainless steel, and superalloy containment systems. Presumably, the extent of this transfer could be reduced by alloying the containment material with stabilizing elements such as titanium.

TABLE II

ROOM TEMPERATURE TENSILE PROPERTIES OF 0.040-INCH THICK Cb-1Zr ALLOY SPECIMENS(1) EXPOSED FOR 1,000 HOURS AT 1400°F IN POTASSIUM CONTAINED IN TYPE 321SS AND TYPE 316SS CAPSULES

| Capsule Material and Specimen No. | 0.2% Yield Strength(2), psi | Ultimate Tensile Strength, psi | Elongation In/In, % |
|---|---|---|---|
| Type 316SS-1 | 46,700 | 56,000 | 20 |
| Type 316SS-2 | 40,300 | 57,000 | 15 |
| Type 321SS-3 | 29,600 | 49,300 | 30 |
| Type 321SS-4 | 25,300 | 42,800 | 36 |
| Pre-test | 23,300 | 40,000 | 37 |

---

(1) MCN 454

(2) Strain Rate 0.005 Inch Per Inch Through 0.2% Yield Point.

# V. FUTURE PLANS

## A. Task I

1. Install tungsten caps on the $Al_2O_3$ probes and initiate the stress-corrosion capsule test.

2. Based on results obtained from this test, fill, seal, and initiate testing of a second capsule.

## B. Task II

1. Complete the post-test evaluation for the bimetallic capsule program.

## REFERENCES

(1) Work Performed Under NASA Contract NAS 3-2140, "Evaluation of AS-55 Alloy and Other High Strength Columbium Alloys for Alkali Metal Containment," July 25, 1962 to September 15, 1964, General Electric Company, Cincinnati, Ohio.

(2) DiStefano, J. R. and Hoffman, E. E., "Corrosion Mechanisms in Refractory Metal-Alkali Metal Systems," Atomic Energy Review, (1964), Vol. 2, No. 1, p 20.

## DISTRIBUTION LIST
## QUARTERLY AND FINAL PROGRESS REPORTS

Contract NAS3-6012

NASA
Washington, D.C. 20546
Attention: Arvin Smith (RNW)

NASA
Washington, D.C. 20546
Attention: James J. Lynch (RNP)

NASA
Washington, D.C. 20546
Attention: George C. Deutsch (RR)

NASA
Washington, D.C. 20546
Attention: Dr. Fred Schulman (RNP)

NASA
Scientific & Technical Information Facility
Box 5700
Bethesda, Maryland 20014
Attention: NASA Representative (2 + Repro.)

NASA
Ames Research Center
Moffet Field, California 94035
Attention: Librarian

NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attention: Librarian

NASA Langley Research Center
Hampton, Virginia 23365
Attention: Librarian

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Librarian

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Dr. Bernard Lubarsky (SPSD)

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Roger Mather (NPTB) 500-309

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: G. M. Ault

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: R. L. Davies (NPTB) (2)

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: John E. Dilley (SPSPS)

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: John Weber - Technology
Utilization Office

NASA
Lewis Research Center
2100 Brookpark Road
Cleveland, Ohio 44135
Attention: T. A. Moss

Report Distribution List NAS3-6012 - Quarterly and Final - (Continued)

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Dr. Louis Rosenblum (MSD)

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: Report Control Office
M.S. 5-5

NASA
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention: V. Hlavin M.S. 3-14
(Final Only)

NASA
Manned Spacecraft Center
Houston, Texas 77001
Attention: Librarian

NASA
George C. Marshall Space Flight Center
Huntsville, Alabama 38512
Attention: Librarian

NASA
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 99103
Attention: Librarian

NASA
Western Operations Office
150 Pico Boulevard
Santa Monica, California 90400
Attention: John Keeler

National Bureau of Standards
Washington, D.C. 20225
Attention: Librarian

Flight Vehicle Power Branch
Air Force Aero-Propulsion Lab
Wright-Patterson Air Force Base, Ohio
Attention: Charles Armbruster
ASRPP-10

Flight Vehicle Power Branch
Air Force Aero-Propulsion Lab
Wright-Patterson Air Force Base, Ohio
Attention: T. Cooper

Flight Vehicle Power Branch
Air Force Aero-Propulsion Lab
Wright-Patterson Air Force Base, Ohio
Attention: Librarian

Flight Vehicle Power Branch
Air Force Aero-Propulsion Lab
Wright-Patterson Air Force Base, Ohio
Attention: Mr. George E. Thompson
APIP-1

Flight Vehicle Power Branch
Air Force Aero-Propulsion Lab
Wright-Patterson Air Force Base, Ohio
Attention: Mr. George Sherman API

Army Ordnance Frankford Arsenal
Bridesburg Station
Philadelphia, Pennsylvania 19137
Attention: Librarian

Bureau of Ships
Department of the Navy
Washington, D.C. 20225
Attention: Librarian

Bureau of Weapons
Research & Engineering
Materials Division
Washington, D.C. 20225
Attention: Librarian

U.S. Atomic Energy Commission
Technical Reports Library
Washington, D.C. 20545
Attention: J. M O'Leary (2)

U.S. Atomic Energy Commission
P.O. Box 1102
Middletown, Connecticut 06458
Attention: A. J. Alexander
Canel Project Office

U.S. Atomic Energy Commission
Germantown, Maryland 20767
Attention: Col. E. L. Douthett
SNAP 50/SPUR Project Office

U.S. Atomic Energy Commission
Germantown, Maryland 20767
Attention: H. Rochen
SNAP 50/SPUR Project Office

U.S. Atomic Energy Commission
Germantown, Maryland 20767
Attention: Major Gordon Dicker
SNAP 50/SPUR Project Office

U.S. Atomic Energy Commission
Technical Information Service Extension
P.O. Box 62
Oak Ridge, Tennessee 27831 (3)

U.S. Atomic Energy Commission
Washington, D.C. 20545
Attention: M. J. Whitman

Office of Naval Research
Power Division
Washington, D.C. 20225
Attention: Librarian

U.S. Naval Research Laboratory
Washington, D.C. 20225
Attention: Librarian

Advanced Technology Laboratories
Division of American Standard
369 Whisman Road
Mountain View, California 94040-2
Attention: Librarian

Aerojet General Corporation
P.O. Box 296
Azusa, California 91702
Attention: Librarian

Aerojet General Nucleonics
P.O. Box 77
San Ramon, California 94583
Attention: Librarian

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 36th Street
Phoenix, Arizona 85000
Attention: Librarian

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 36th Street
Phoenix, Arizona 85000
Attention: E. A. Kovacevich

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 36th Street
Phoenix, Arizona 85000
Attention: Mr. John Dannan

AiResearch Manufacturing Company
9851-9951 Sepulveda Boulevard
Los Angeles, California 90045
Attention: Librarian

Argonne National Laboratory
9700 South Cross Avenue
Argonne, Illinois 60440
Attention: Librarian

Atomics International
8900 DeSoto Avenue
Canoga Park, California 91303
Attention: Librarian

AVCO
Research and Advanced Development Dept.
201 Lowell Street
Wilmington, Massachusetts 01800
Attention: Librarian

Babcock and Wilcox Company
Research Center
Alliance, Ohio 44601-2
Attention: Librarian

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43200
Attention: Librarian

The Bendix Corporation
Research Laboratories Division
Southfield, Detroit, Michigan 48200
Attention: Librarian

The Boeing Company
Seattle, Washington 98100
Attention: Librarian

Brookhaven National Laboratory
Upton, Long Island, New York 11973
Attention: Librarian

Carborundum Company
Niagara Falls, New York 14300
Attention: Librarian

Chance Vought Aircraft, Inc.
P.O. Box 5907
Dallas 22, Texas 75222
Attention: Librarian

Clevite Corporation
Mechanical Research Division
540 East 105th Street
Cleveland, Ohio 44108
Attention: N. C. Beerli,
Project Administrator

Convair Astronautics
5001 Kerrny Villa Road
San Diego, California 92111
Attention: Librarian

Curtiss-Wright Corporation
Research Division
Quehanna, Pennsylvania
Attention: Librarian

E. I. duPont de Nemours and Co., Inc.
Lavoisier Library
Experimental Station
Wilmington, Delaware 19898
Attention: Librarian

E. I. duPont de Nemours and Co., Inc.
Lavoisier Library
Experimental Station
Wilmington, Delaware 19898
Attention: E. M. Mahla

Eitel McCullough, Incorporated
301 Industrial Way
San Carlos, California
Attention: Leonard Reed

Electro-Optical Systems, Inc.
Advanced Power Systems Division
Pasadena, California 91100
Attention: Librarian

Ford Motor Company
Aeronutronics
Newport Beach, California 92660
Attention: Librarian

General Atomic
John Jay Hopkins Laboratory
P.O. Box 608
San Diego, California 92112
Attention: Librarian

General Electric Company
Atomic Power Equipment Division
P.O. Box 1131
San Jose, California

General Electric Company
Missile and Space Vehicle Department
3198 Chestnut Street
Philadelphia, Pennsylvania 19104
Attention: Librarian

General Electric Company
Vallecitos
Vallecitos Atomic Lab.
Pleasanton, California 94566
Attention: Librarian

General Dynamics/Fort Worth
P.O. Box 748
Fort Worth, Texas 76100
Attention: Librarian

General Motors Corporation
Allison Division
Indianapolis, Indiana 46206
Attention: Librarian

Hamilton Standard
Division of United Aircraft Corporation
Windsor Locks, Connecticut
Attention: Librarian

Report Distribution List NAS3-6012 - Quarterly and Final - (Continued)

Hughes Aircraft Company
Engineering Division
Culver City, California 90230-2
Attention: Librarian

IIT Research Institute
10 W. 35th Street
Chicago, Illinois 60616
Attention: Librarian

Lockheed Missiles and Space Division
Lockheed Aircraft Corporation
Sunnyvale, California
Attention: Librarian

Lockheed Missiles and Space Division
Lockheed Aircraft Corporation
Sunnyvale, California
Attention: Mr. John N. Cox
Staff Engineer

Marquardt Aircraft Company
P.O. Box 2013
Van Nuys, California
Attention: Librarian

The Martin Company
Baltimore, Maryland 21203
Attention: Librarian

The Martin Company
Nuclear Division
P.O. Box 5042
Baltimore, Maryland 21220
Attention: Librarian

Martin Marietta Corporation
Metals Technology Laboratory
Wheeling, Illinois

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139
Attention: Librarian

Materials Research and Development
Manlabs, Incorporated
21 Erie Street
Cambridge, Massachusetts 02139

Materials Research Corporation
Orangeburg, New York
Attention: Librarian

McDonnel Aircraft
St. Louis, Missouri 63100
Attention: Librarian

MSA Research Corporation
Callery, Pennsylvania 16024
Attention: Librarian

North American Aviation
Los Angeles Division
Los Angeles, California 90009
Attention: Librarian

Oak Ridge National Laboratory
Oak Ridge, Tennessee
Attention: W. H. Cook

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
Attention: W. C. Thurber

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
Attention: Dr. A. J. Miller

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
Attention: Librarian

Pratt & Whitney Aircraft
400 Main Street
East Hartford, Connecticut 06108
Attention: Librarian

Pratt & Whitney Aircraft
CANEL
P.O. Box 611
Middletown, Connecticut 06458
Attention: Librarian

Pratt & Whitney Aircraft
CANEL
P.O. Box 611
Middletown, Connecticut 06458
Attention: Dr. Robert Strouth

Republic Aviation Corporation
Farmingdale, Long Island, New York
Attention: Librarian

Rocketdyne
Canoga Park, California 91303
Attention: Librarian

Solar
2200 Pacific Highway
San Diego, California 92112
Attention: Librarian

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206

Superior Tube Company
Norristown, Pennsylvania
Attention: Mr. A. Bound

Sylvania Electrics Products, Inc.
Chem. & Metallurgical
Towanda, Pennsylvania
Attention: Librarian

Temescal Metallurgical
Berkeley, California 94700
Attention: Librarian

Thompson Ramo Wooldridge, Inc.
Caldwell Res Center
23555 Euclid Avenue
Cleveland, Ohio 44117
Attention: Librarian

Thompson Ramo Wooldridge, Inc.
Caldwell Res Center
23555 Euclid Avenue
Cleveland, Ohio 44117
Attention: G. J. Guarnieri

Thompson Ramo Wooldridge, Inc.
New Devices Laboratories
7209 Platt Avenue
Cleveland, Ohio 44104
Attention: Librarian

Union Carbide Corporation
Stellite Division
Kokomo, Indiana
Attention: Librarian

Union Carbide Nuclear Company
P.O. Box X
Oak Ridge, Tennessee 37831
Attention: X-10 Laboratory
Records Department (2)

Union Carbide Metals
Niagara Falls, New York 14300
Attention: Librarian

Mr. W. H. Podolny
United Aircraft Corporation
Pratt & Whitney Division
400 W. Main Street
Hartford 8, Connecticut

United Nuclear Corporation
Five New Street
White Plains, New York 10600-5
Attention: Librarian

Union Carbide Corporation
Parma Research Center
P.O. Box 6115
Cleveland, Ohio 44101
Attention: Technical Information
Services

Vought Astronautics
P.O. Box 5907
Dallas, Texas 75222
Attention: Librarian

Wah Chang Corporation
Albany, Oregon
Attention: Librarian

Westinghouse Electric Corporation
Astronuclear Laboratory
P.O. Box 10864
Pittsburgh, Pennsylvania 15236
Attention: Librarian

Westinghouse Electric Corporation
Materials Manufacturing Division
RD#2 Box 25
Blairsville, Pennsylvania
Attention: Librarian

Westinghouse Electric Corporation
Astronuclear Laboratory
P.O. Box 10864
Pittsburgh 36, Pennsylvania
Attention: R. T. Begley

Westinghouse Electric Corporation
Aerospace Electrical Division
Lima, Ohio
Attention: R. W. Briggs

Westinghouse Electric Corporation
Research & Development Center
Pittsburgh, Pennsylvania 15235
Attention: Librarian

Wyman-Gordon Company
North Grafton, Massachusetts
Attention: Librarian

Zirconium Corporation of America
Solon, Ohio
Attention: Librarian